Photonics Technology for Space Communications Applications

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introduction

Photonics technology offers a multitude of applications and major benefits in the development of future spaceborne communications systems with high performance and' low mass/si ze requirements. These applications include not only signal distribution/control functions, but also optical signal processing, phased array antennas, sensors, instruments, and gyros. Figure 1 illustrates the insertion of photonic technology into spacecraft. Photonic technology offers the capability to link all spacecraft data, control, and sensors functions with the mi crowave communications systems within a common architecture. Both radio frequency (RF) and digital signals share a single fiber optic bus thus reducing overall system mass, and volume. Optics] fibers replace common waveguide, coaxial lines and shielded wires while increasing radio frequency interference (RFI) immunity, simplifying routing, and enabling higher degrees of redundancy and/or parallelism.

The series of mi ssions that appear to benefit most are Mars Environmental Survey, Lunar Orbiter, Focused Small Missions, and Submillimeter Research. Specific telecommunications system designs enable simultaneous transmit and receive communications with multiple rovers and micro-orbiters without expending spacecraft resources for the pointing body fixed antennas. Optical sampling, signal processing and computing will simplify communications systems architecture in satelli te systems such as '1'111<SS, and ACTS. The other systems that will benefit i nclude mobile, cable, and fiber optic communication links.

Although there has been a spur of activity in recent years in the technology development of photoni c integrated circuits (PIC) and optoelectronic integrated circuits (OEIC), very limited work has addressed the areas of reliability and cost reduction. Technology maturity, reliability, low cost and flight demonstration arc imperative in the insertion of photonic tech nology in the spacecraft communications applications. Table 1 provides an assessment of the state-of-the-art photonic technology. Integrated photonic components that have been fairly well developed include laser/modulators, optical receivers, laser/amplifiers, and fiber-optic components. The components requiring further R/D include optical samplers/mixers applied to communications, photonic switthing, signal processing, and higher function OEICs, and packages.

Space Communications System Applications

A photonic Ka-band telecommunications system, and an optical-sampler for advanced communications applications are described below.

Ka-band Telecommunications System: Spacecraft and Satellite communications systems use Ka-band frequencies to reduce spacecraft antenna size and mass with increased data rate performance. The current systems are not compatible with fiber optic bus architectures. Such design concepts have been evolving with joint efforts at NASA Lewis Research Center, and Jet Propulsion Laboratory. One such system shown in Figure 2, is a Ka-band phased array telecommunications system consisting of a RF transponder, a photonic transceiver OEIC, an optical signal distribution/control network, and phased array transmit t/receive OEIC elements. The photonic transceiver OEIC consists of dual lasers, and modulators, and photo diode circuits. Several distribution and control network configurations have been identified for specific application requirements. These configurations range from single steerable beam arrays using element level optical delay to more complex multiple beam architectures using optically processed beam forming networks to both distribute and provide the RF phase gradient optically. Each architecture relies upon conversion from optical to Ka-band for transmitting and from Ka-band to optical upon receiving at the aperture level. The photonic Ka-band telecommunications system has a potential to reduce volume by a factor of ten and mass by a factor of three compared to an equivalent electronic implementation.

Optical-sampling Downconverter for Advanced Microwave Communications Applications: Future spaceborne communications transponders require versatile high speed signal processing and detection techniques to downconvert and process radio frequency (RF) signals ranging from 100 MHz to 35GHz. The number of simultaneous orbit/observation missions are expected to increase in the early part of the next century. These missions require simultaneous communications capability at several different frequency bands. The use of optical sampling and detection techniques will offer excellent wideband performance, signal tracking, and reduced volume. Figure 3 shows a block diagram an optical sampling downconverter OEIC consisting of a wideband optical switch, an injection laser diode, a detector-amplifier sample-hold circuit, and a fast rise time pulse generator. The optical-sampling downconverter is capable of transform ng received multi-octave-band microwave signals to intermediate frequencies (1 t ‘) for further processing. Along with ultra-wideband operation, the downconverter promises to provide direct digitization of the RF signal with low conversion loss, high isolation, and low jitter. Additional enhancements promise to simplify the receiver architecture by *eliminating* most of the analog IF circuits, including filters, IF amplifiers, and mixers. This has the potential for low power operation compared to an equivalent electronic high frequency sampling implementation. For example, the electronic sampler designed for Deep Space Network ground receiver requires about 30 W to digitize 8 GHz RF signal. The technique can be applied to deep space transponders, Deep Space Network ground receivers, relay stations, space station receivers, satellite communications systems, and microwave instruments.

Conclusions

The photonic technology is a viable and enabling technology for long-term insertion into spacecraft and satellite communications, signal distribution, phased array, and sensor applications. The technology payoff potentials include high performance, small si ze, low mass, and low power. Additional benefits include high isolation, low loss/dispersion, wide bandwidth, high efficiency, and robust design. Optical sampling and signal processing of RF signals ranging from 100 MHz to 40 GHz is an enhanced technology alternative to conventional electronic processing.

Photonic technology can become more competitive, desi gnable, reliable, and cost-effective by focussing on application oriented research rather than unique one-of-a-kind component development. System hardware development and flight experiments are needed to demonstrate performance advantages of photonic technology applied to space communications applications.

Table 1. State-of-the-art Technology Assessment and Challenges

Photonic Components	Performance	Mass/ Size	Power Consumption	Technology Maturity	Reliability	Cost
1. Laser/Modulator PIC	Very Good	Very Good	Good	Good	Fair	Fair
2. Optical Receiver OEIC	Very Good	Very Good	Very Good	Very Good	Fair	Fair
3. Coherent Optical Receiver OEIC	Good	Very Good	Very Good	Good	Fair	Fair
4. Transceiver OEIC	Good	Very Good	Very Good	Good	Fair	Fair
5 Laser/Amplifier PIC	Good	Very Good	Good	Good	Fair	Fair
6. Fiber-optic Components	Very Good	Best	N/A	Very Good	Good	Good
7. Fiber-optic Amplifiers	Very Good	Very Good	Very Good	Good	Good	Good
8. Modulators	Very Good	Very Good	Very Good	Good	Good	Good
9. Multiplexers/DeMultiplexers	Very Good	Very Good	Very Good	Good	Fair	Fair
10. Optical Samplers/Mixers	Fair	Very Good	Very Good	Fair	Fair	Poor
11. Photonic Switching & Signal Processing PICs	Good	Very Good	Very Good	Fair	Fair	Poor
12. PIC & OEIC Packages	Good	Very Good	N/A	Fair	Fair	Fair

Legend: Poor, Fair, Good, Very Good, Best

PIC - Photonic Integrated circuit

OEIC - Opto-Electronic Integrated circuit

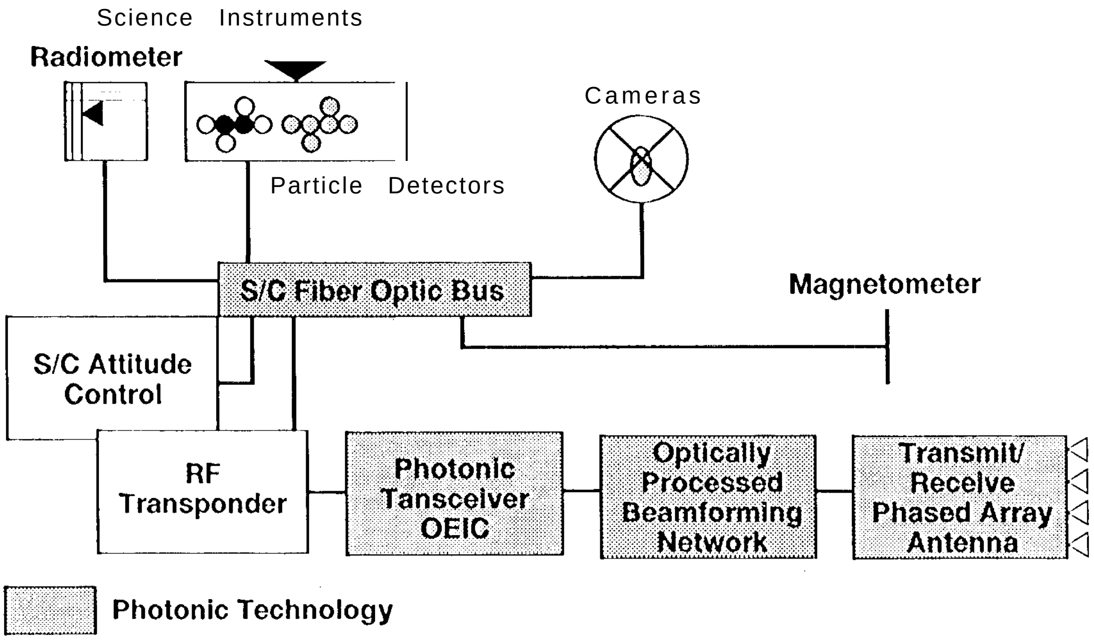

Figure 1. A System Block Diagram Illustrating the Insertion of Photonic Technology into Spacecraft

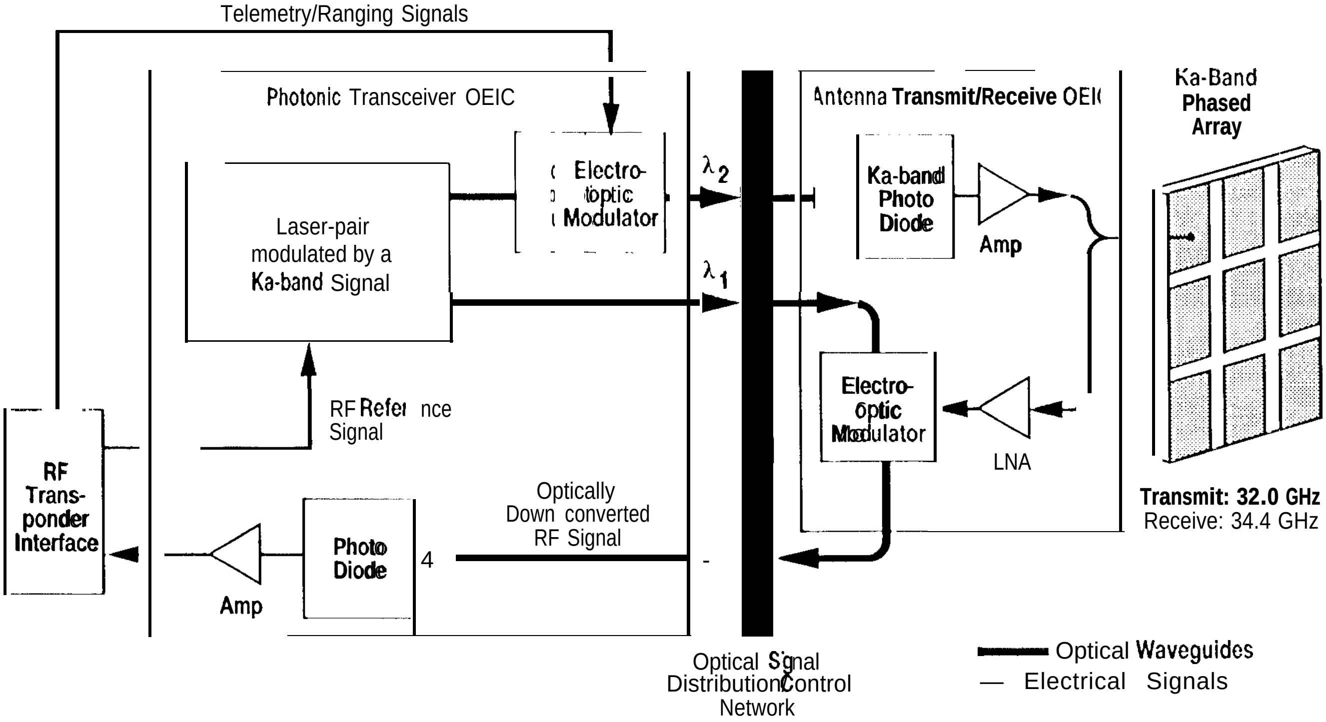

Figure 2. Photonic Ka-Band Spacecraft Telecommunications Systems Concept

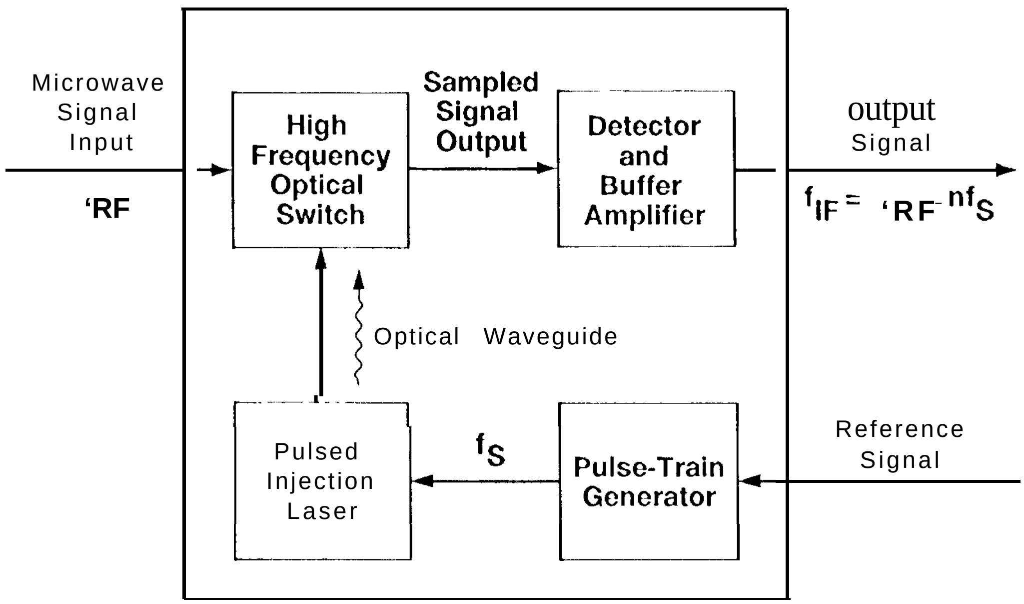

Figure 3. Optical Sampling Downconverter and Signal Processor